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A Shock Tube Technique for Investigating Droplet Electrification in Ionized Flows

MP 64-138

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1 INTRODUCTION

Under contract NASw-941, MITHRAS, Inc. is currently investigating a method for achieving radio communication through the plasma sheath which surrounds a vehicle in hypervelocity flight through the atmosphere. In this method the electron concentration in the plasma is reduced by injecting a mixture of a heat-absorbing fluid (e. g. helium, water, or propane) and a electrophilic gas (e. g. sulfur hexafluoride or carbon tetrachloride). In mixing with the flow in the plasma sheath the injected gas both reduces its temperature and removes electrons by attachment to electrophilic atoms or molecules.

The work under the current contract is concerned specifically with one aspect of the overall method, namely the electron attachment process to electrophilic substances. It is largely experimental in nature and is being carried out in the small shock tube sketched in Figure 1. The driven section of this tube consists of a 20-foot constant-area tube followed by an expanding wedge nozzle emptying into a dump tank. The test gas is premixed with the air in this section before the shock tube is fired. Electron concentrations are measured at various stations along the nozzle with a microwave interferometer. A measure of the effectiveness of each gas is obtained by noting the decrease in the electron concentration as it is added in increasing proportion. Figure 2 shows some preliminary data of this sort obtain for SF_6, CCl_4 and Cl_2. Under our current contract NASw-941, we plan to refine these measurements and extend them to include more additives and a range of thermodynamic conditions and initial electron concentrations.

In conversation with members of the RAM group at LRC, NASA, we have concluded that it would be desirable to obtain comparative results with water droplets. In the case of water injection droplet electrification is a possible mechanism for electron removal and may be much more efficient than negative ion formation.

Using the results of a study for ONR on the breakup of raindrops by shockwaves, we have conceived a method for placing a cloud of droplets in the ionized nozzle flow. What follows is a brief description of this technique, preceded by a discussion of the wave processes in the shock tube.

2. BASIC WAVE PROCESSES IN THE SHOCK TUBE AND NOZZLE

The basic wave processes in the shock tube and wedge nozzle are illustrated in the X-t diagram of Figure 3. In addition to the shock waves and contact surface, this diagram shows the particle paths of several samples of air picked up by the initial shock wave at various stations along the tube.

The principal features of the flow are:

A. the initial shock wave which moves at constant speed along the constant-area tube and then slows down in the nozzle.

B. the upstream-facing "starting shock" in the nozzle which is swept downstream by the flow. This is analogous to the starting shock in an ordinary wind-tunnel nozzle.

C. the contact surface between the driver and driven gases. This moves at a constant speed along the constant-area tube and then accelerates in the nozzle.

D. the shock wave driven ahead of the accelerating contact surface.

Samples of air picked up at different points along the shock tube are subjected to radically different thermodynamic processes, as indicated by the pertinent particle paths. An instrument examining the air passing by a fixed location in the nozzle sees first the region between the two shocks A and B. In this region the conditions are not constant. Initially the instrument sees air which has been compressed by the initial shock but not expanded. Somewhat later the air passing the instrument has been compressed in the constant area tube, expanded in the nozzle and compressed again by the starting shock.

Next the instrument views the region between B and D. There conditions are uniform, all this air having been compressed in the constant-area section and then expanded through the same area-ratio in the nozzle. This constitutes the desired test sample.

Finally the instrument views the air in the region between C and D, which has been processed initially in the same manner as the test sample but then has been overtaken by the shockwave D.

The time history of any property measured at a fixed point in the nozzle is thus quite complex. The region of interest B-D is however quite easy to identify because it is bounded by two shocks, beyond which the pressure and temperature are quite a bit higher. Figure 3 is an oscilloscope record of microwave transmission through the ionized air, showing clearly the test region as a valley between two peaks. The second peak may merge with the signal from the driver gas which follows the contact surface.

3. THE PROPOSED TECHNIQUE FOR WATER INJECTION

The technique proposed is an outgrowth of a recent test program for ONR on the breakup of raindrops. In this program we generated raindrops in the MIT 8" x 24" shock tube using a "leaky faucet" of hypodermic tubing. Drops were formed at frequencies between 10 and 15 cycles in the diameter range between 1.5 mm and 2.5 mm. Since this covered the range desired, no attempts were made to extend it, but there is no reason to believe that it could not be extended simply by using larger or smaller tubing.

Drop breakup was photographed with a Fastax camera at the rate of 13,000 frames/sec. A typical breakup of a 0.07 - inch drop is shown in Figure 5. Beyond the sixth frame, the drop has been broken up into a roughly cylindrical cloud of fine droplets about 1.5 inches long and 0.4 inches in diameter.

The time required for the drop to breakup is a simple function of diameter and dynamic pressure behind the shock.

The form of this function can be derived using a model similar to that developed in NASA TN D 2424 for jet breakup and we find

$$t_b \approx \frac{23\ d}{q}$$

where t_b is the breakup time in milliseconds

d is the drop diameter in inches

q is the dynamic pressure in psi

This technique can clearly be used to fill the central region of our 1 1/2 inch shock tube with a cloud of droplets. (of water or any other liquid). The following required conditions can be computed from our ONR test program and shock tube tables;

dynamic pressure at

$5\ mm/\mu sec$ and $P_1 = 20\ mm \approx 500\ psi$

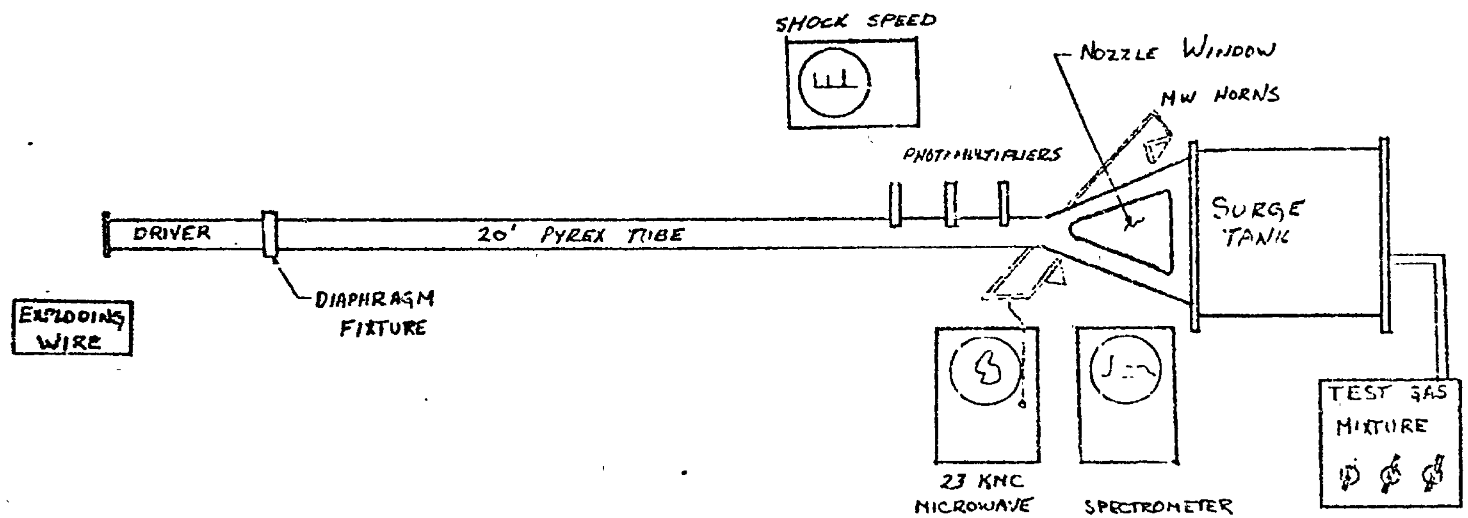
breakup time of a 0.07 " drop ≈ 70 μ sec

Since this drop size can conveniently be generated and the breakup time is of the order of the test time, the technique is applicable. In practice a specific choice of parameters would be made so that the drop breakup process would occupy the region between A and B on the wave diagram. The droplet velocity along the tube would be negligible. Ionized air will then flow through a cloud of droplets in a direct simulation of the flight conditions of interest.

It only remains to show that the shock tube can be fired while a drop is near the axis of the tube. The vertical velocity of the falling drop there is about 5 ft/sec. A tolerance of ± 0.1 inches in drop location thus corresponds to a tolerance of 20 milliseconds in shock arrival time. Test have shown that the scatter in the combustion and diaphragm opening times of our shock tube are only ± 0.5 milliseconds. The timing problem can therefore be solved by firing the shock tube on a signal derived from the appearance of a water drop in the test section.

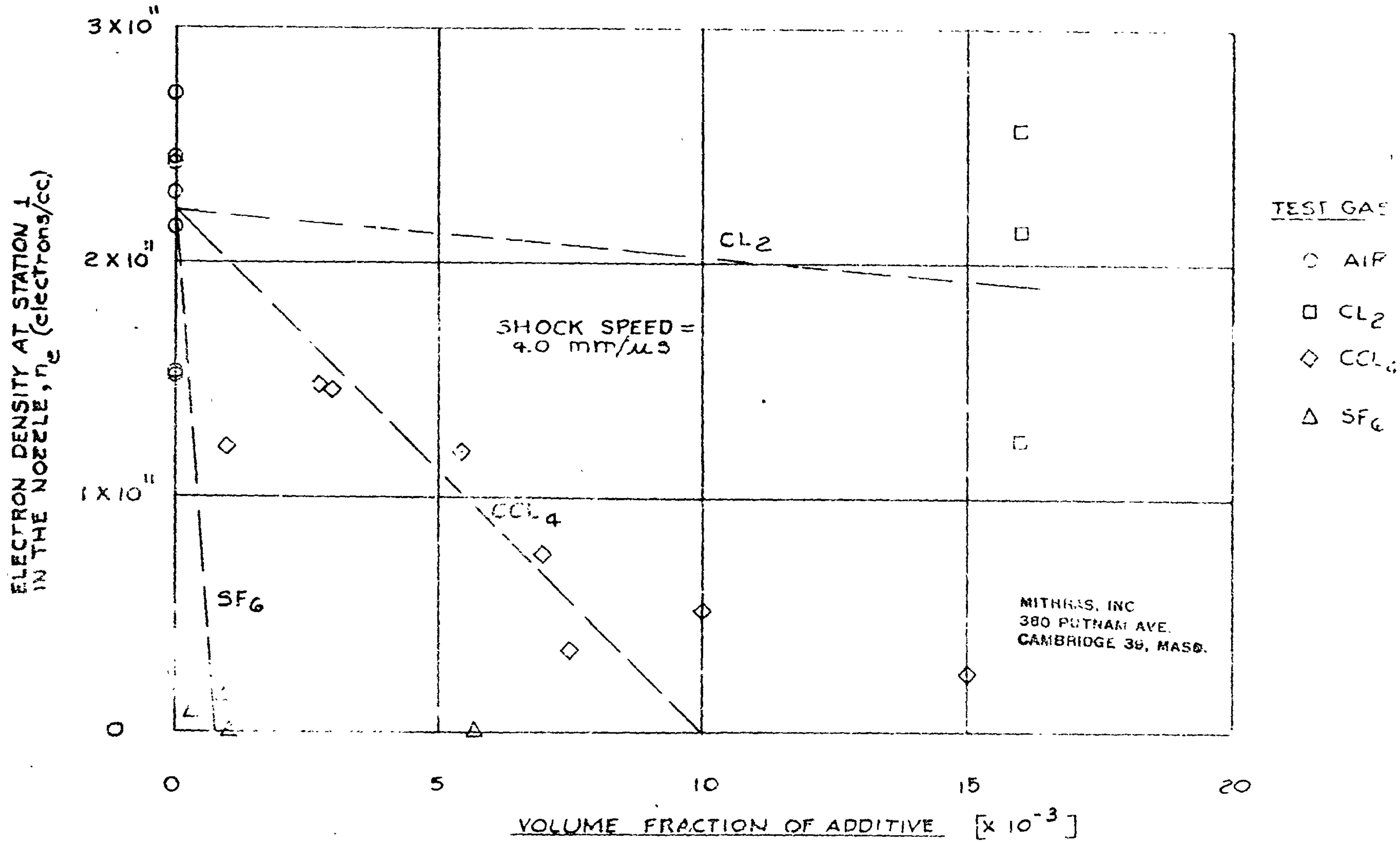
FIGURE 1

MITHRAS A SHOCK TUBE



SHOCK TUBE MEASUREMENTS OF ELECTRON ATTACHMENT IN MIXTURES OF VARIOUS GASES WITH AIR

FIGURE 2.



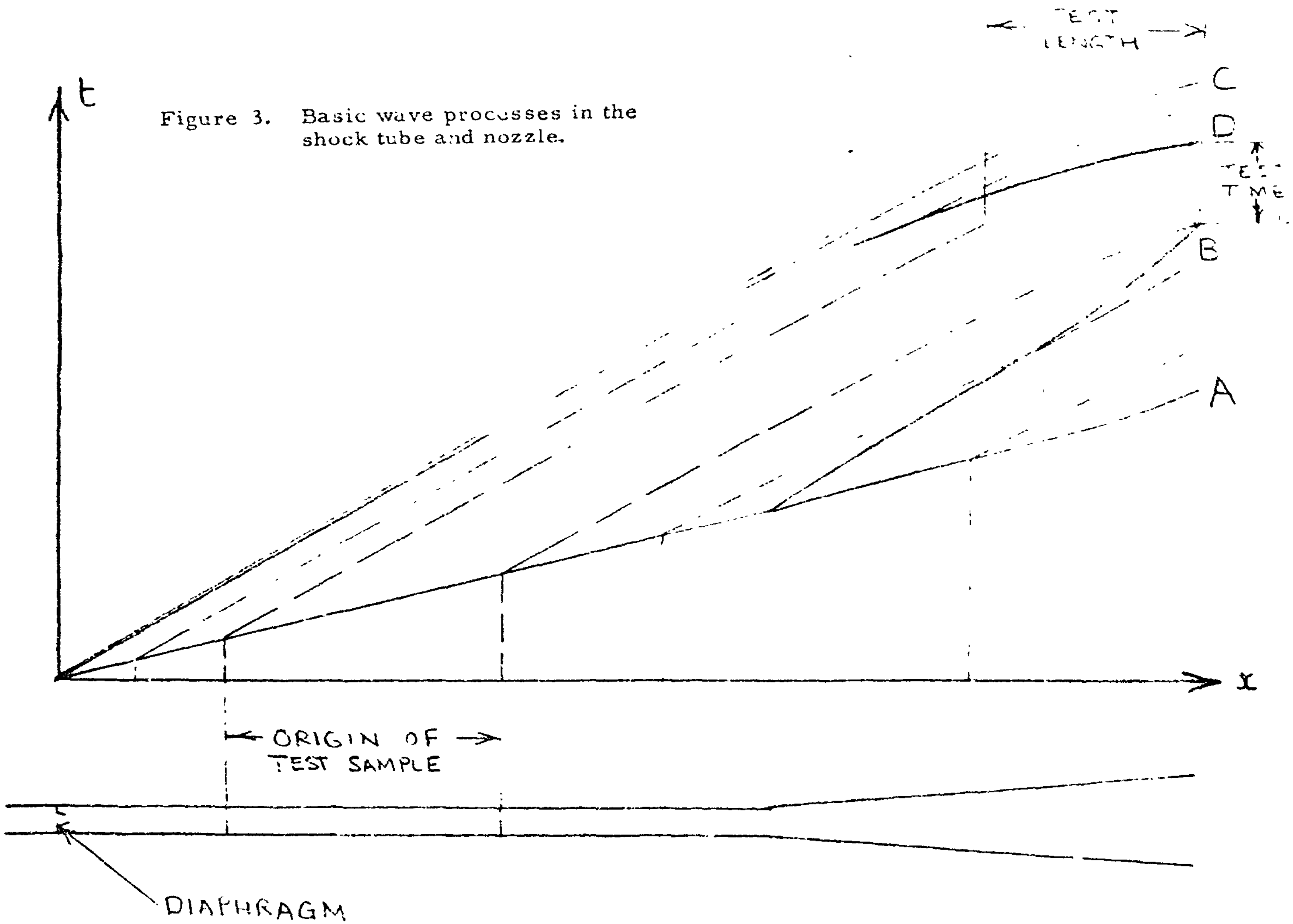
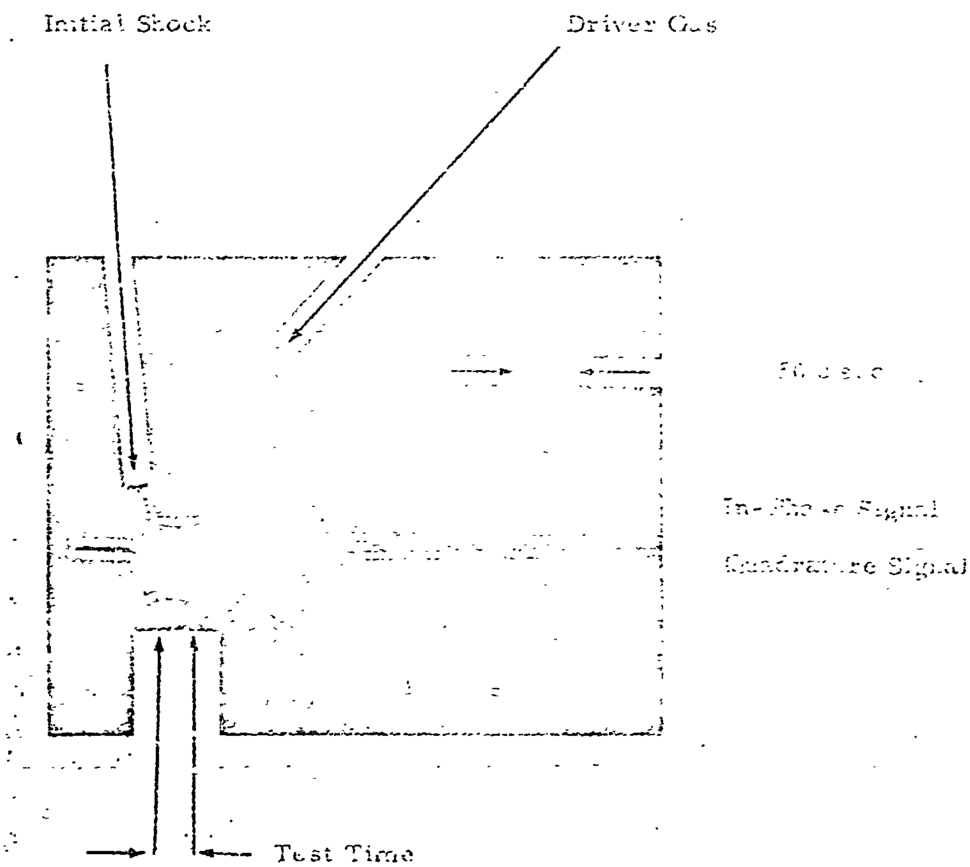


Figure 3. Basic wave processes in the shock tube and nozzle.



Sweep Speed = 50 µsec/cm

Figure 4. Oscilloscope trace of microwave interferometer signal in the shock tube nozzle.

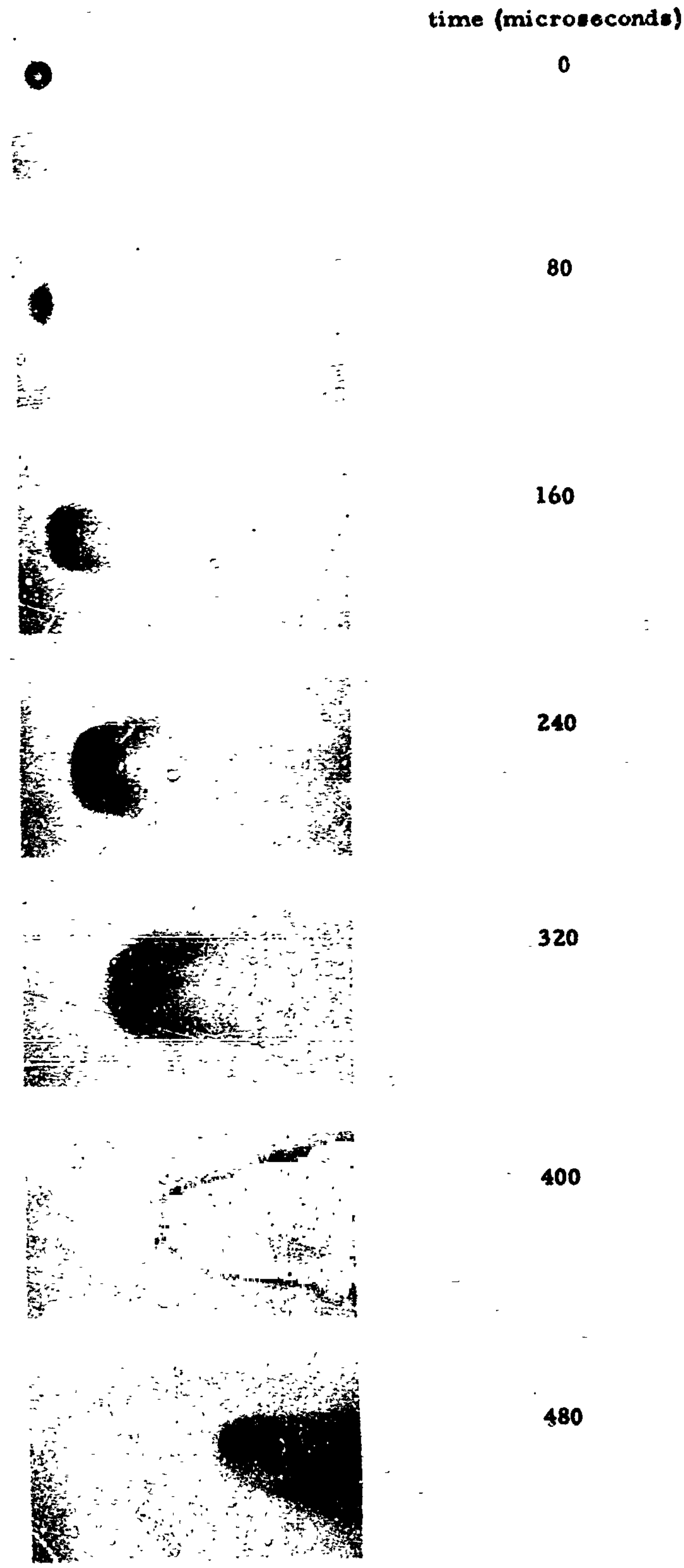


Figure 5. Liquid drop breakup and dispersion in a shock tube.